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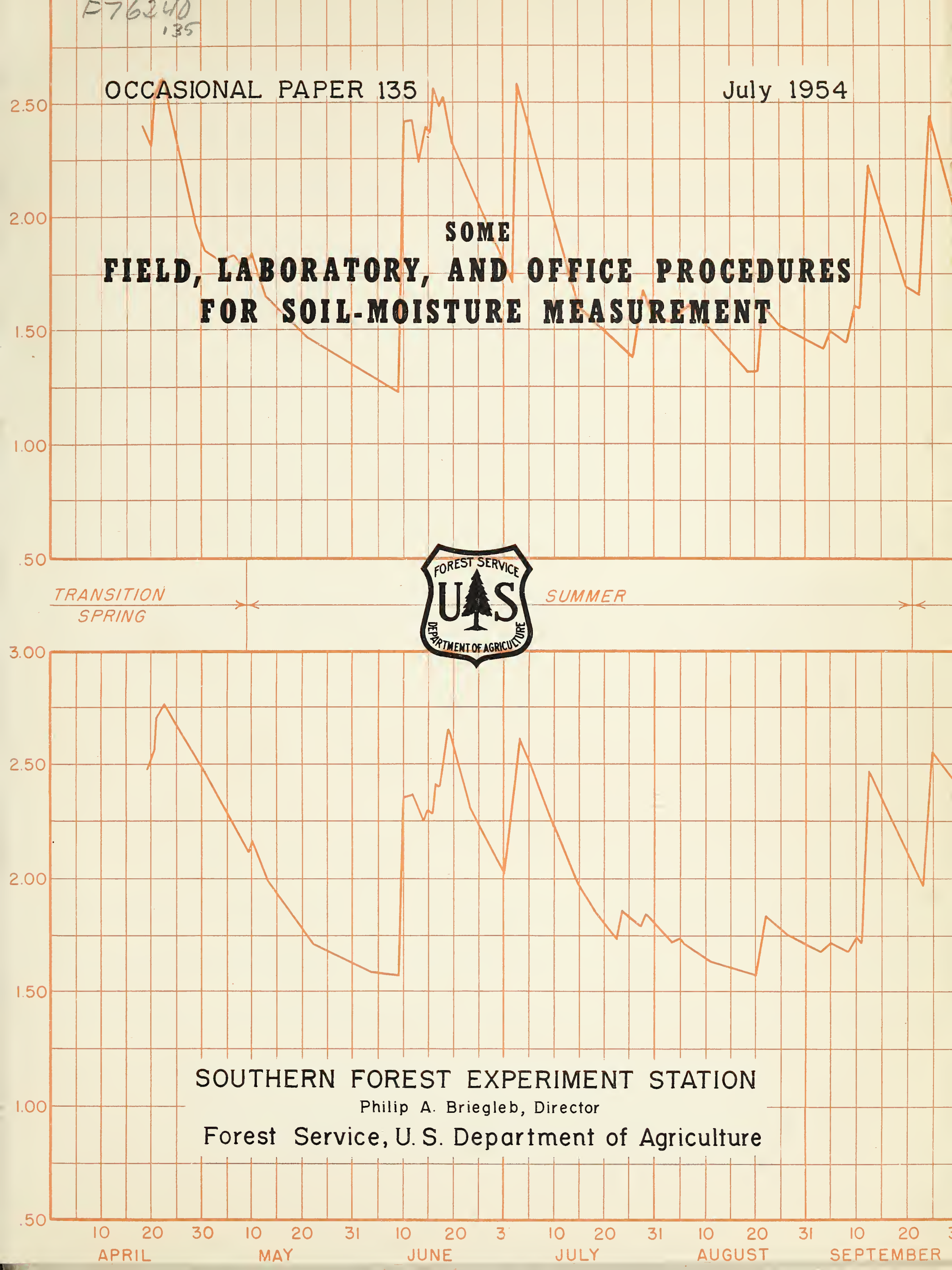
SOME FIELD, LABORATORY, AND OFFICE PROCEDURES FOR SOIL-MOISTURE MEASUREMENT



SOUTHERN FOREST EXPERIMENT STATION

Philip A. Briegleb, Director

Forest Service, U. S. Department of Agriculture

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CONTENTS

SOME FIELD, LABORATORY, AND OFFICE PROCEDURES FOR SOIL-MOISTURE MEASUREMENT

To an ever-increasing extent, soil-moisture records are considered essential to evaluations of plant-soil-water relations governing the growth and yield of forest and agricultural crops. The use of water by different types of vegetation growing in different types of soil, seasonal storage opportunities for soil moisture under various kinds of land use, the extent of root occupancy and growth--in these and a host of related problems soil moisture is one of the measured variables.

Measuring soil moisture is a relatively simple task, but it does require a modicum of experience with the instruments and techniques. The articles in this paper, like those in an earlier publication,[1/] represent an accumulation of experience of this kind.

The first two of the eight articles deal with bulk density, the first, how to measure it; the second, how to evaluate it. Both are related to the volumetric expression of soil-moisture content. The third paper reveals the differences in moisture-tension data secured from core and bulk samples. The next three papers describe equipment to facilitate gravimetric sampling and reading electrical resistance units. The seventh compares laboratory and field calibration of fiberglas units. The last deals with roots, their measurement and concentration --a subject closely related to the evaluation of soil-moisture records from different soil depths.

1/ Soil-moisture measurement with the fiberglas instrument. Southern Forest Expt. Sta. Occas. Paper 128, 48 pp. 1953.

PROCEDURES AND EQUIPMENT FOR DETERMINING SOIL BULK DENSITY

W. M. Broadfoot

One of the important phases of the soil-moisture studies of the Vicksburg Infiltration Project has been the determination of bulk density. Defined as the ratio of the weight of oven-dry soil to the volume it occupied in the field, bulk density is expressed in grams per cubic centimeter. Its use is principally for converting moisture content from percent by weight to depth or area-inches.

Between March 1951 and December 1952 over 1,200 individual bulk density determinations were made on Mississippi River alluvium and loess near Vicksburg. Of these, approximately 90 percent were by three methods. No attempt was made to compare one method or procedure with another, for the overall objective was to obtain, most expediently, enough values at the various study sites to permit expression of soil-moisture records in inches depth. However, in the course of obtaining the values, certain procedures were found superior to others and some improved equipment was developed.

Description of Procedures

The three procedures evaluated and used in the bulk density determinations were designated "block," "San Dimas," and "air-picnometer."

Block procedure

This procedure involves measurement and excavation of a block of soil 12 inches square by 3 inches in depth.

First, a 14- by 14-inch plot of soil is selected and marked off on the ground as a sampling area. All organic debris is carefully removed down to the mineral soil. A spike is driven into the ground close to the 14-inch square; its purpose is to serve as a point from which the depth of successive 3-inch sample layers can be measured.

Figure 1.--Taking a soil sample by the block method.

A shallow trench, approximately the width of a spade, is dug around the sampling area, thereby forming a soil column 14 inches square. A wooden frame 14 inches square (inside dimension) 1/ is gently forced down over the soil column until the top of the frame is just above the soil surface. The frame is leveled and the vertical distance from the top of the reference spike to the top of the frame is measured and recorded. The outline of the 12-inch sample square is then scratched on the surface of the 14-inch square.

The volume of the first sample must now be corrected for any unevenness in the surface of the soil. This can be done by placing a straightedge across the frame and measuring, at several points within the 12-inch square, the vertical distance between the straightedge and the soil surface. The average distance, multiplied by the area of the block, gives the proper correction.

Next, the soil is carefully cut away and removed from underneath the frame until the top of the frame can be lowered exactly 3 inches below the first measurement from the reference spike. The frame is again leveled, and the soil block trimmed to final dimensions, down to the top of the frame (fig. 1).

1/ The frame must not be warped or twisted. The model in figure 1 was made of nominal 2 by 4 lumber.

The soil sample is then removed flush with the top of the frame and placed in moisture-proof bags. Successive samples below the surface are obtained similarly (except that no correction is made for uneven surface), with the frame being forced down exactly 3 inches each time a sample is taken.

Representative portions are taken for moisture determinations from each block-sample. After the block of soil and the sample portions are weighed, bulk density is computed:

$$\text{Bulk density} = \frac{\text{Oven-dry weight of soil in grams}}{\text{Volume of soil block in cubic centimeters}}$$

San Dimas procedure

In this procedure a sampler [2/] is used to obtain a core of soil 2.72 inches in diameter and 3 inches in depth, and with a volume of 288 cubic centimeters.

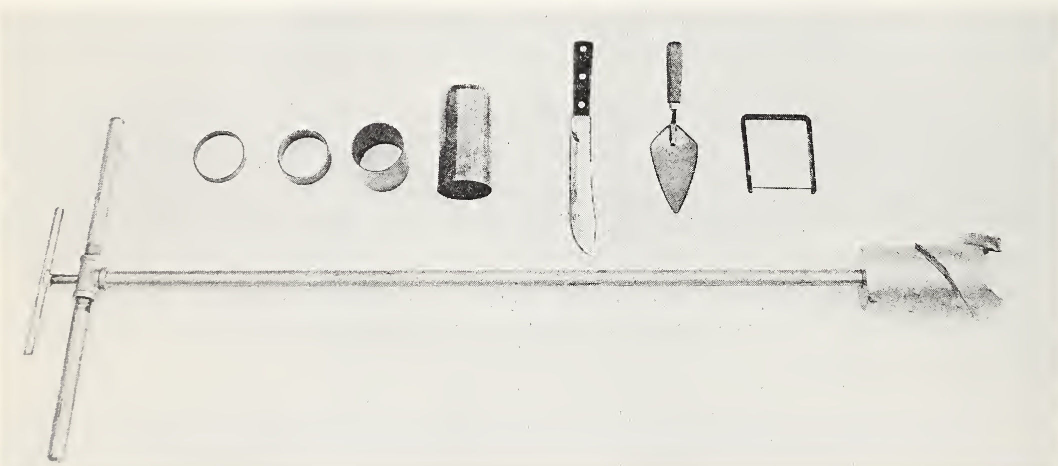

Figure 2. --The San Dimas sampler and equipment used in determining bulk density. (Photo by Waterways Experiment Station, Corps of Engineers.)

This sampler (fig. 2) has an outer cylinder equipped with spiral flanges with sharp cutting points, and an inner cylinder with 3 removable

2/ The sampler was designed at the San Dimas Experimental Forest, California Forest and Range Experiment Station, U. S. Forest Service. Information for making it was furnished by J. S. Horton.

brass sleeves. The largest sleeve is the size of the desired core; the two smaller sleeves fit above and below the large one, and serve as buffers to protect the soil core. Flanges are provided on the outer cylinder to cut the soil and bear it upward so that binding is diminished. When the handle attached to the outer cylinder is rotated, the inner cylinder is forced downward into the soil. Rotation of the inner cylinder is prevented by holding back on the handle of the rod enclosed in the main shaft. The design permits the inner cylinder to penetrate undisturbed soil.

After the sampler is removed from the sampling hole, the inner cylinder is pushed out of the outer cylinder and then detached from the rod. Next the sleeves containing the soil core are removed from the inner cylinder and the soil is trimmed flush with the ends of the largest sleeve. Then the core is pushed out of the sleeve into a 16-ounce soil can and taken to the laboratory, where it is oven-dried at 105° C. The head of the sampler is substantially longer than the desired core: about 5 inches of soil are removed in order to secure a 3-inch core. Where successive 3-inch samples are desired, as at the Vicksburg Infiltration Project, they must be taken alternately from 2 sample holes.

Calculation:

$$\text{Bulk density} = \frac{\text{Oven-dry weight in grams of soil}}{288}$$

Air-picnometer procedure

The air-picnometer was introduced by Russell (2)[3/] to measure the volume of air-filled pores in soil. He pointed out that if the procedure is carried a step further and the weight of the soil obtained, then moisture content and bulk density for most soils can be estimated from nomographs.

The sample cores used in making the determinations at Vicksburg were taken from excavated pits by means of a Coile-type sampler (1) in conjunction with a cylindrical brass sample holder that fits closely into the air-picnometer tube. The sample holder is 2 inches in inside diameter and 1-3/8 inches high (fig. 3).

After the soil core is obtained, it is placed in the air-picnometer. Pressure is applied and the mercury scale reading recorded. Then the core (plus cylinder) is weighed, after which it may be discarded.

3/ Underscored numbers in parentheses refer to Literature Cited, page 11.

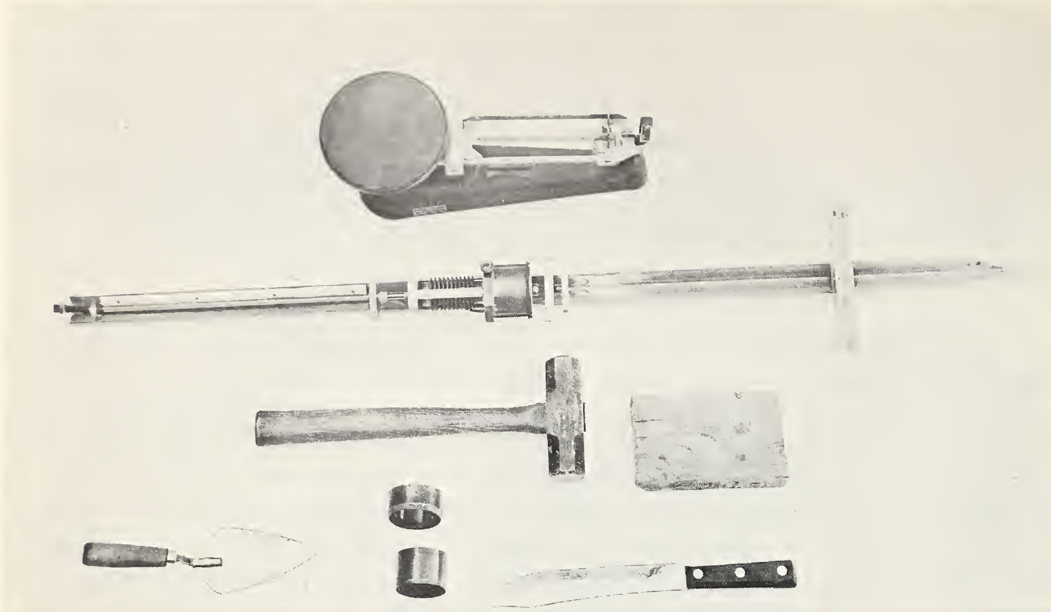

Figure 3. --The air-picnometer and equipment for use in determining bulk density. (Photo by Waterways Experiment Station, Corps of Engineers.)

Calculations:

(a) Obtain air space from a previously constructed calibration curve (2).

(b) On a nomograph [4/] relating air space, moisture content, and field weight of core (fig. 4), connect with a straightedge the percent of air space and the weight of the core (without cylinder), and read the percent of moisture by weight.

(c) On a bulk-density nomograph (fig. 5), connect weight of core sample and percent of water and read the bulk density along the extended straightedge.

4/ Nomographs in figures 4 and 5 were developed by Dr. W. A. Raney, Mississippi Agricultural Experiment Station, State College, Mississippi. Calculations for these nomographs are based on a soil specific gravity of 2.65; therefore the nomographs cannot be used to determine moisture content and bulk density of soils with a high organic content.

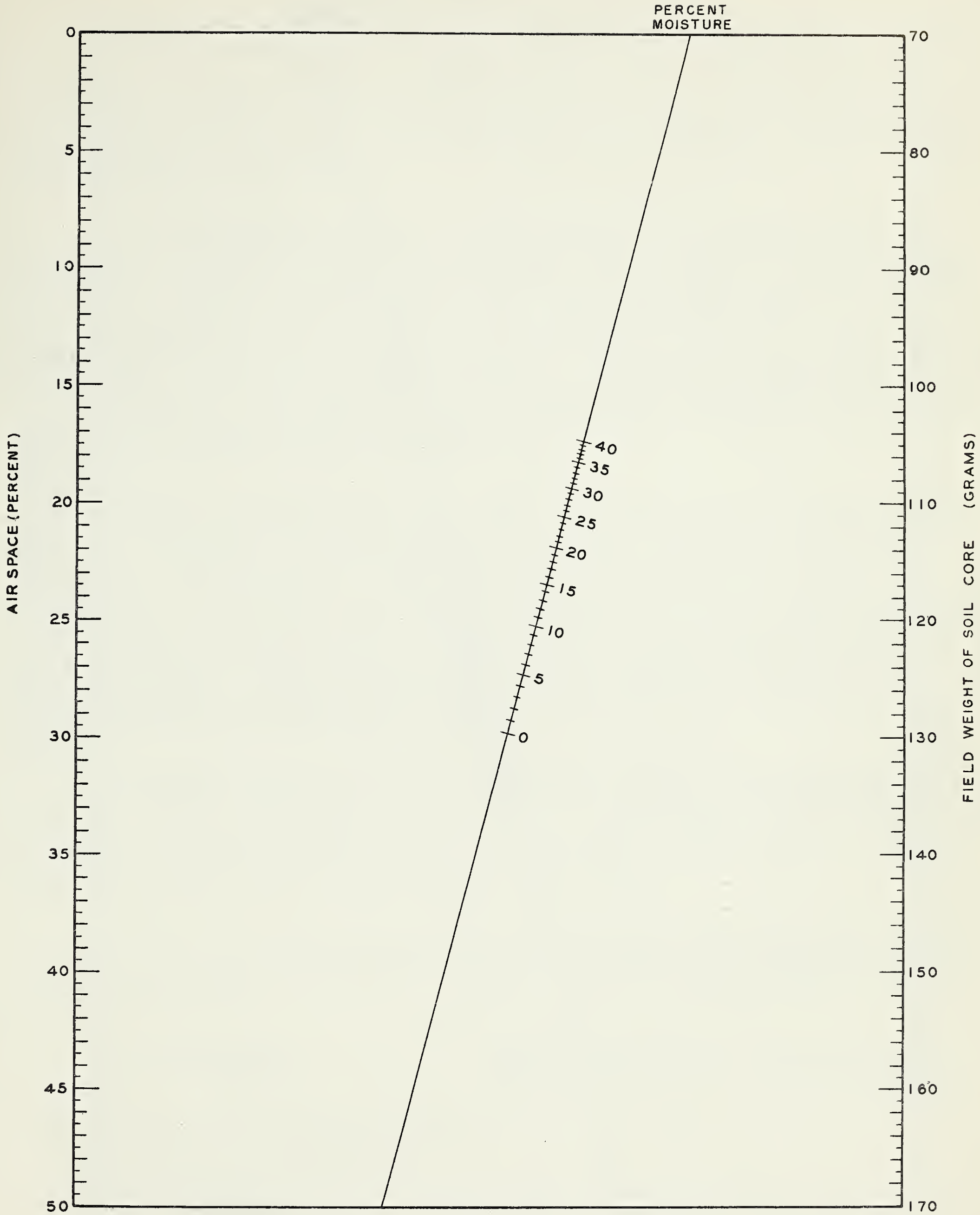

Figure 4.—Nomograph for estimating percent of moisture by weight from weight of soil core and air space.

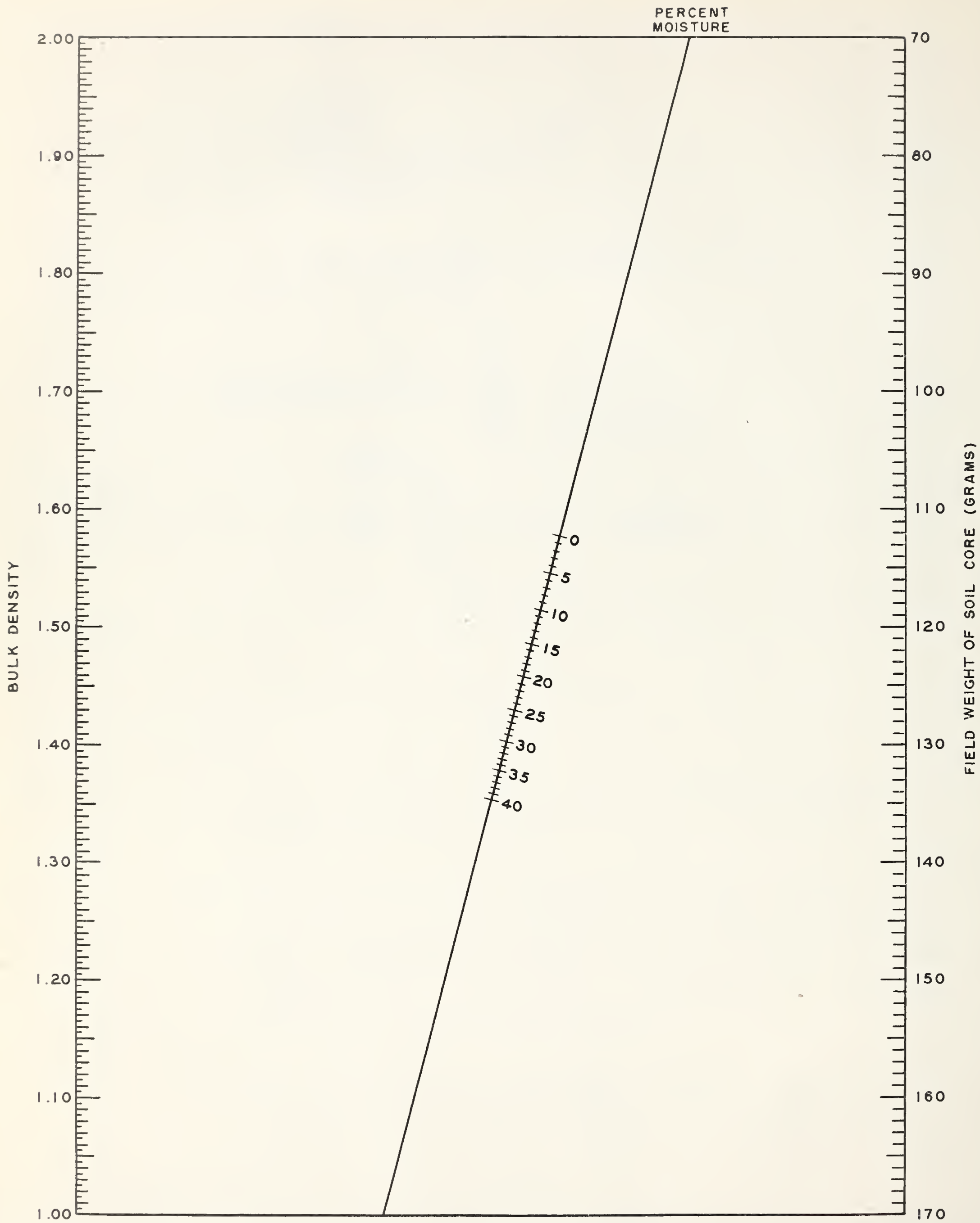

Figure 5.— Nomograph for estimating bulk density from weight of soil core and moisture content.

Comparison of Procedures

The procedures were evaluated by comparing mean bulk densities and by taking into consideration such factors as disturbance of sampling area (as the need to dig pits), time required to take the sample, personal skill required to make the determination, and utility of the procedure in dry soil.

The block method gave slightly lower bulk densities than the San Dimas and air-picnometer methods. For instance, in a comparison of 168 blocks and 149 San Dimas cores from four sites, the mean block value was 1.32 and the mean San Dimas value was 1.39, a difference significant at the one-percent level. In another comparison, block samples taken at various depths at one site were 0.04 lower than comparable air-picnometer values, a difference which was also significant at the one-percent level.

These results, however, are very likely biased. Block samples are feasible only when the soil is moist, and moist soil gives lower bulk density values than dry soil. Subsequently, in what was perhaps the most direct comparison, picnometer cores were taken out of 30 blocks of soil from 4 experimental sites, and the bulk density values obtained by the two procedures were treated statistically as paired samples. In this comparison, the mean differences were not significant at the five-percent level.

The San Dimas values tended to run higher than air-picnometer values, but the differences were small. In one case, the San Dimas bulk densities averaged 0.02 greater than the picnometer values, a nonsignificant difference at the five-percent level.

The other factors taken into consideration in evaluating the procedures were rated on a 1-2-3 system, with 1 representing the best and 3 the poorest:

Rating factor	Block	San Dimas	Air-picnometer
Disturbance of sampling area	3	1	3
Compression or disturbance of soil sample	1	3	2
Personal skill required	3	1	2
Utility in dry soil	3	3	1
Time required	3	2	1

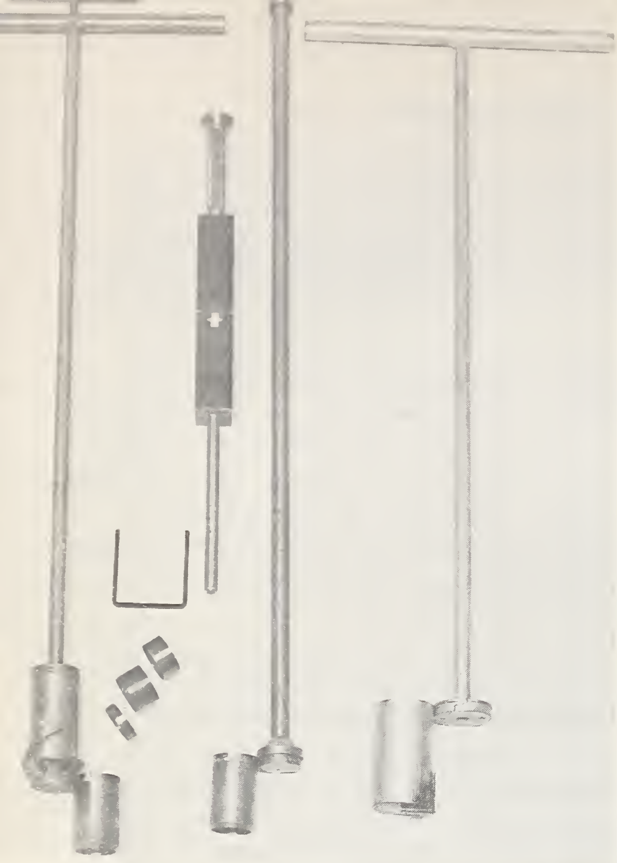

Figure 6. --Two types of samplers and a hole-cleaner for obtaining soil cores for bulk-density determination. (Photo by Waterways Experiment Station, Corps of Engineers.)

Considering all points or factors, the San Dimas and air-picnometer procedures appear about equally superior to the block procedure.

Sampling Equipment

The combined advantages of the San Dimas and air-picnometer procedures were realized by developing sampling devices similar to the San Dimas sampler but with a cylinder of the same diameter as the air-picnometer cylinder. Used with the air-picnometer, the sampler eliminates digging a pit and thus permits thorough sampling with little disturbance of an area.

Two samplers and a hole cleaner were made (fig. 6). One sampler is patterned after the San Dimas but is scaled down so that the inner cylinder (with its sleeves) fits the air-picnometer. The smaller size, and the fact that the pitch of the augering flanges is not so steep as on the original San Dimas model, makes it easier to get this sampler into the soil. The other sampler is driven into the soil with a King-tube type hammer. The inner cylinders of the two samplers are interchangeable. The "Little San Dimas" sampler is used in moist soil and the hammer-driven model in dry soil. The hammer-driven sampler has a small hole through the driving head, with an outlet near the head of the shaft, to permit escape of air. The outer cylinders and handles of both samplers are marked off in 3-inch increments, so that with either instrument successive 3-inch soil layers can be easily sampled from a single sampling hole.

The wire cheese cutter and the hole-cleaner (fig. 6) are accessories. The cutter is used to separate the buffer sleeves, and soil within the sleeves, from the sample. Sometimes it is preferable to slip the buffer sleeves off the ends of the core and trim the soil flush with the ends of the core cylinder with a sharp, straight-edged butcher knife.

The hole-cleaner has the same outside diameter as the outside edges of the cutting flanges on the Little San Dimas. When used with a hammer-driven sampler it serves as a hole-widener as well as a hole-cleaner. Sharp cutting knives welded to the bottom and side of the instrument remove the soil and scoop it into the detachable soil-collecting compartment. The cleaner is marked off in the same 3-inch increments as the samplers.

Field tests have shown these devices to be a rapid and convenient means of obtaining soil samples at various depths with very little disturbance of the experimental area. The core samples can be used without the air-picnometer for bulk density determinations. For soils containing over 5 percent organic matter it is recommended that the bulk density be determined by drying and weighing. For this computation, the oven-dry weight of the soil is divided by 71 cc, the volume of the core sleeve or sample.

Literature Cited

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1936. Soil samplers. Soil Sci. 42: 139-142.

(2) Russell, M. B.
1949. A simplified air-picnometer for field use. Soil Sci. Soc. Amer. Proc. 14: 73-76.

RELATION OF SOIL BULK DENSITY TO MOISTURE CONTENT AS IT AFFECTS SOIL-MOISTURE RECORDS

K. G. Reinhart

In many studies of the hydrologic cycle which include measurement of soil moisture, it is necessary to convert soil-moisture content in percent of oven-dry weight to inches depth of water. This paper points out some of the relationships and difficulties involved, and suggests procedures for making the conversion.

Moisture content in percent of the oven-dry weight of soil does not disclose the actual amount of water present. However, multiplying this value by bulk density gives water volume per cubic unit of soil volume. Then multiplication by soil depth converts cubic measurement to linear:

$$\left(\frac{\text{water volume}}{\text{soil volume}}\right)(\text{soil depth}) = \frac{\text{water volume}}{\text{soil area}} = \text{water depth}$$

Bulk density, volume weight, and apparent specific gravity are practically synonymous. In this paper the term bulk density[1/] will be used. Defined as the ratio of the weight of oven-dry soil to the volume it occupies in the field, it is generally expressed in grams per cubic centimeter, or $B = \frac{\text{oven-dry weight of soil in grams}}{\text{field volume of soil in cubic centimeters}}$

Bulk density is not easy to determine, even for small areas. It is affected by texture, organic content, and structure; these factors usually remain fairly constant, at least within short periods of time. It is also affected by changes in moisture content of the soil because of swelling and shrinking caused by addition and loss of water. An analysis of this phenomenon is warranted because it results in changes of bulk density within short periods and thus complicates determining the average bulk density value applicable to any specified depth over a given soil area.

1/ It is the term recommended by the Soil Science Society of America (4).

Shrinking and Swelling of Soils

The shrinking and swelling of soil is accompanied by both vertical and horizontal changes. Shrinkage in a vertical plane may lower the soil surface; this lowering can be detected by appropriate methods (5). Vertical shrinkage may form voids below the soil surface, but the weight of the soil above tends to reduce the size of such voids and observation indicates that they have negligible volume. Shrinkage in a horizontal plane, however, causes cracks quite apparent at the soil surface.

Vertical shrinkage results in the soil occupying a smaller volume than it occupied before the shrinkage took place; the volume represented by the difference in elevations before and after shrinkage becomes a part of the atmosphere. Since the same mass of soil occupies a smaller volume, the bulk density must necessarily be increased.

Horizontal shrinkage, on the other hand, has no effect on average bulk density as long as void spaces are included in the soil volume. If the bulk density values are to be used in computation of area inches of water, they must represent the whole area, including that portion given over to cracks. If samples are taken only between cracks, bulk density values will be too high. Where soil cracks are large, conventional procedures for obtaining samples cannot be used and sampling becomes more difficult.

Because shrinkage affects bulk density and its determination, it also affects soil-moisture records. Its influence can be described according to the type of soil-moisture sampling: either gravimetric or by electrical-resistance instruments.

When soil-moisture records are taken by gravimetric means, the same depth increments of soil are removed at each sampling regardless of fluctuations in the elevation of the soil surface due to shrinking and swelling. This procedure is proper, for the sole objective is to obtain periodic moisture measurements for specified depths. The bulk density of each sample may be obtained for conversion of soil-moisture content from percent by weight to inches depth. Because of the time and effort required, this is rarely done. Another procedure sometimes advocated is to use bulk densities obtained from bulk density-moisture regressions. Horizontal shrinkage presents no problem in gravimetric sampling so long as bulk density values used for conversion are derived from samples which include the cracks in the soil where they exist.

The effects of shrinking and swelling are of greater import to the measurement of soil moisture when electrical-resistance units are used.

As with gravimetric sampling, horizontal shrinkage or expansion has little effect. Vertical shrinkage or expansion results in the depth or thickness of the layer represented by a soil-moisture unit becoming a fraction over or under the depth measured at the time of installation. The relationship of moisture content in inches (d) with moisture in percent of dry weight (M), bulk density (B), and thickness (D) of soil layer is given in the following equation:

$$d = \frac{(M)\,(B)\,(D)}{100}$$

If a given mass of soil varies only in vertical dimension, (B)(D) will be constant, since $B = \frac{\text{constant oven-dry weight}}{(\text{constant soil area})(\text{variable soil depth})}$, and $(B)\,(D) = \frac{(\text{constant weight})(D)}{(\text{constant area})\,(D)} = \frac{\text{constant weight}}{\text{constant area}}$. Hence (d) can always be calculated as $\frac{(M)\,(B)\,(D)}{100}$, regardless of fluctuation in (B) and (D). Consequently, any pair of values for (B) and (D) can be used provided they are both determined under the same moisture conditions. For example, assume that the bulk density of a certain 3-inch layer of soil is 1.30 at a moisture content of 30 percent by weight (this would be 1.17 inches of water in the 3-inch layer). Now suppose that shrinkage results in a bulk density of 1.35 at 10 percent. As the bulk density has increased by 135/130, the same mass of soil must now occupy only 130/135 as much space. Since this change is entirely in a vertical direction, the height of the layer has been reduced to (3) (130/135) inches, or from 3 to 2.889 inches. The inches of water in the layer at 10 percent moisture content is therefore

$$\frac{(10)\,(1.35)\,(2.889)}{100} = 0.390 \text{ inch}$$

It is readily seen that the same answer will be obtained if the values of 1.30 and 3, instead of 1.35 and 2.889, are used for bulk density and soil depth, respectively.

To assume that at 10 percent moisture the bulk density had actually increased to 1.35 but that the depth of the soil layer remained the same would give too high a value; i.e., $\frac{(10)\,(1.35)\,(3)}{100} = 0.405$ inch.

The above reasoning is based on the premise that the soil moisture units installed at various depths in the soil retain their position with respect to the adjacent soil despite any slight raising or lowering of the soil layers with shrinking and swelling.

The single value of bulk density used in conversion from percent to inches should correspond to the bulk density existing when the units are installed and the soil depths are measured. Both installation of units and bulk density sampling are most easily accomplished when the soil is moist, at field capacity or slightly below (3).

In field calibration of electrical-resistance units, gravimetric samples are obtained. As the thickness of the layer represented by each unit varies with moisture content, the depth of sampling should be adjusted if the amount of shrinking and swelling is great enough to have any appreciable effect. This question will be considered below.

Determining Amount of Shrinking and Swelling

Determination of the amount of shrinking and swelling is of interest with respect to both the calibration sampling with electrical-resistance units and, as already noted, the method using gravimetric samples alone.

In the vicinity of Vicksburg, over 1,200 bulk density samples were obtained at different depths and over a range of moisture contents in loess silt loams and water-deposited clay. Linear regressions and correlation coefficients were computed to determine the nature and degree of relationship. The methods were somewhat similar to those reported by Bethlahmy (1).

The regression coefficients obtained varied widely by location and depth, often without apparent reason. Typical regressions for three sites are given in figure 1. Of 90 regressions computed, 28 were statistically significant and 66 showed decreasing bulk density

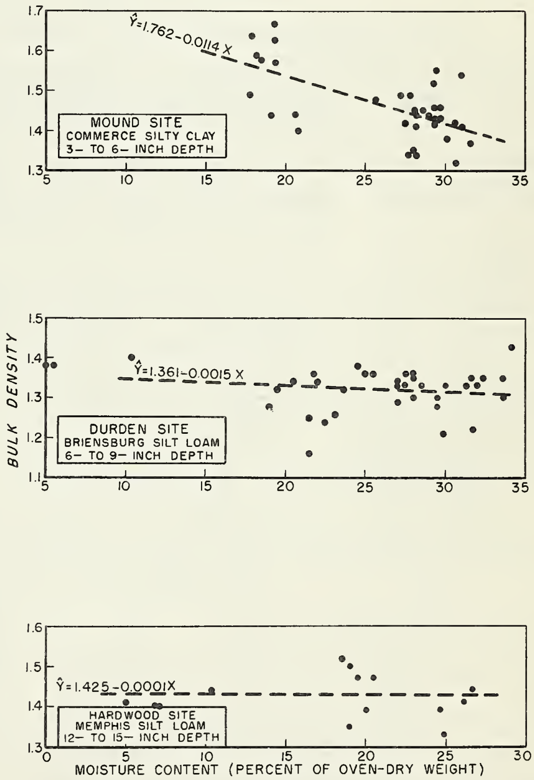

Figure 1. --Typical regressions of bulk density on moisture content.

with increase in moisture content. Significance in at least five cases (including the upper regression in figure 1), however, was affected because samples were taken (at low moisture contents) between the soil cracks and thus gave bulk density values that were too high. These regressions might be interpreted as implying the amount of shrinking and swelling of the soil. Such a conclusion would be improper, as will be shown below.

In the regressions, moisture content was expressed in percent by weight. Samples differing in bulk density, but containing the same amount of water per unit volume, will have different moisture contents since both amount of water and weight of soil per unit volume, or bulk density, enter into computation of moisture percent by weight. This is illustrated in figure 2. Thus, if numerous samples are taken from an area having the usual variation in bulk density, and with the soil at the same moisture per unit volume, a regression of bulk density on moisture content will be obtained even though no shrinking or swelling has occurred.

To investigate this effect further, regressions of bulk density on moisture content in percent by volume were compared with those in percent by weight, for the 0- to 3-inch and 12- to 15-inch depths at one site. The two regressions for each depth were determined from the same samples. In the following equations, Y is bulk density, X is moisture percent by weight, and Z is moisture percent by volume.

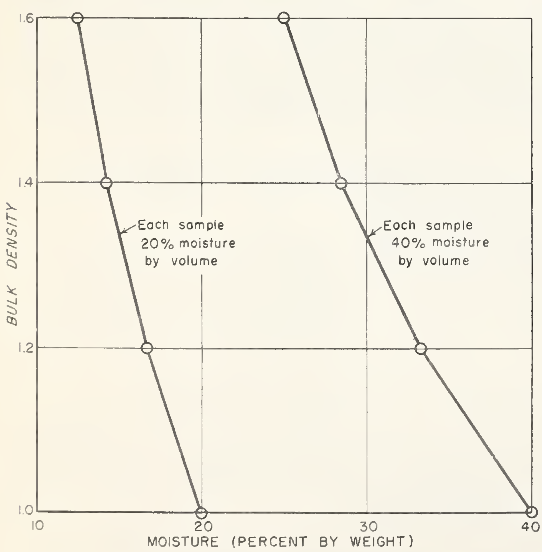

Figure 2. --Relationship of moisture content by weight to bulk density, when moisture percent by volume is constant.

Regressions for the 0- to 3-inch depth were:

$Y = 1.81 - .016X$, with a highly significant correlation coefficient, $-.789$

$Y = 1.76 - .010Z$, with a significant correlation coefficient, $-.555$

Regressions for the 12- to 15-inch depth were:

$Y = 1.55 - .005X$, with significant correlation coefficient, $-.419$

$Y = 1.48 - .002Z$, without significant correlation coefficient, $-.217$

For the 0- to 3-inch depth, when percent-by-weight values were used, 62 percent of the variation was attributable to difference in moisture content; using percent-by-volume values reduced this to 31 percent. Comparable values for the 12- to 15-inch depth were 18 and 5 percent.

These correlations show that a stronger influence of moisture content on bulk density is indicated when moisture content is expressed as percent by weight rather than as percent by volume. The fact that weight of the soil appears in the numerator of bulk density and in the denominator of moisture percent by weight accounts for the stronger inverse relation (or negative correlation) between these two.

The natural variation in bulk density within a given area results in varying amounts of pore space being available for the storage of water. If a constant value for the specific gravity of soil is assumed, a maximum or saturation moisture content in percent by weight can be computed for any given bulk density. The formula is:

$$\text{Maximum moisture content} = \frac{\text{specific gravity} - \text{bulk density}}{(\text{specific gravity})(\text{bulk density})} \times 100$$

$$= \frac{100}{\text{bulk density}} - \frac{100}{\text{specific gravity}}$$

Thus, a soil of bulk density 1.60, for example, will be saturated at 25 percent moisture content by weight; a soil of bulk density 1.30 will be saturated at 39 percent. Intermediate bulk densities will be saturated at intermediate moisture contents because of the inverse relationship between bulk density and maximum moisture percent. This is illustrated for two soils in figure 3. In this figure, the solid lines show the maximum moisture content possible for any bulk density within the range encountered (a soil specific gravity of 2.65 is assumed) and the dashed lines represent the regression determined from field sampling. Similarities in slopes of the two lines are very noticeable.

The inverse relation between moisture content and bulk density is obvious at saturation ($MC = \frac{100}{B} - \text{constant}$). At lower moisture contents it is less apparent. The question is largely one of relative distribution of pore sizes in any two samples having a different bulk density. If the only difference lies in the amount of pore space of the sizes drained by gravity, there would be no difference in the moisture content (by volume) in two samples subjected to the same tension at field capacity or below. However, if the sample having lower bulk density also has

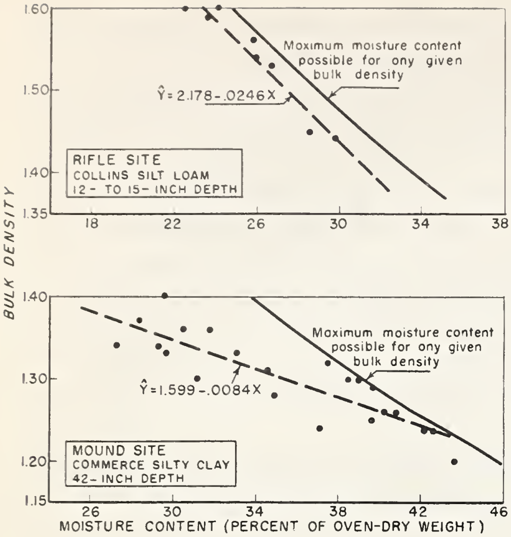

Figure 3.--Typical regressions of bulk density on moisture content under wet conditions.

more pore space in the smaller size classes, it will contain more water at a given tension than the denser sample. Since the latter condition seems more likely, and since samples obtained at any one time from the same soil depth tend to have the same tension, a correlation between bulk density and moisture content can be expected entirely apart from any shrinking or swelling that might be associated with moisture loss or moisture gain.

To provide information on this relationship with the soil at field capacity, an analysis was made of tension-moisture content data. At each of several depths at three sites, five replicate soil cores were obtained from the same pit. Bulk density and moisture-tension were determined for each core. Regression and correlation coefficients between moisture content in percent by weight at 60 cm. tension (field capacity) and bulk density were computed for each depth (table 1). Almost one-third of the correlation coefficients and regression coefficients were statistically significant. Thirty out of 31 of the regression coefficients were negative, an indication that, on the average, the sample having a lower bulk density will have a higher moisture content in percent by weight at field capacity. Thus random field samples taken in this part of

Table 1.--Coefficients of regression of bulk density on moisture content in percent by weight at 60-cm. tension (field capacity) and corresponding correlation coefficients

Soil depth (inches)	Durden site				Hardwood site		Pine site			
	Pit No. 1		Pit No. 2				Pit No. 1		Pit No. 2	
	Correlation coefficient	Regression coefficient	Correlation coefficient	Regression coefficient	Correlation coefficient	Regression coefficient	Correlation coefficient	Regression coefficient	Correlation coefficient	Regression coefficient
0-3	-0.70	-0.016	-0.99**	-0.019**			-0.96*	-0.018*	-0.78	-0.014
3-6	-.66	-.008	-.19	-.004	-.75	-.010	-.12	-.005	-.94*	-.032*
6-9	-.83	-.027	-.24	-.007	-.86	-.030				
9-12	+.98**	+.058**	-.64	-.041	-.90*	-.025*	-.30	-.035	-.999**	-.028**
12-15					-.98**	-.029**				
15-18	-.46	-.010	-.82	-.022						
18-21					-.93*	-.017*				
21-24	-.74	-.018	-.09	-.0002	-.95*	-.054*	-.77	-.024	-.30	-.007
28-31	-.72	-.011	-.32	-.008	-.26	-.003				
40-43	-.63	-.023	-.89*	-.019*						

**Significant at 1 percent level
*Significant at 5 percent level

the moisture range would show a regression of bulk density on moisture content even though no shrinking or swelling of the soil were involved.

Regressions for three degrees of soil moisture are illustrated in figure 4. The "wet soil" regression was computed from 24 samples taken on January 3, 1952, at one site and at various depths to 42 inches. The "intermediate soil" line was based on 22 samples taken on October 25 and 26, 1951, from the same depths. The "dry soil" line was computed from 16 samples taken by 3-inch depths to 12 inches on July 16 and 17, 1951.

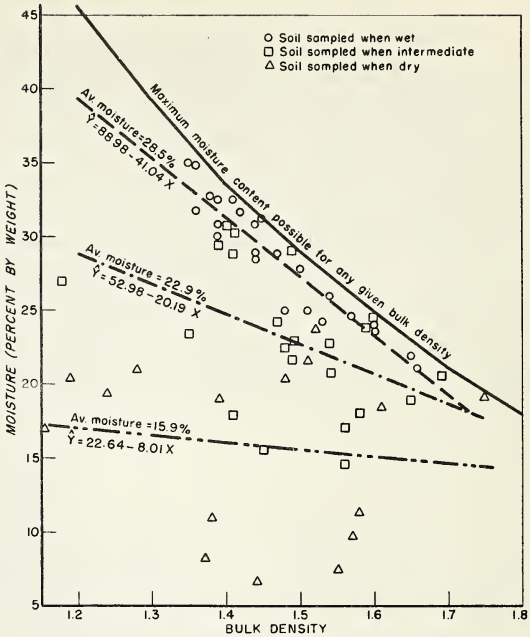

Figure 4. --Regression of moisture on bulk density under wet, intermediate, and dry conditions.

Individual points deviated little from the wet soil line, more from the intermediate soil line, and most from the dry soil line. A t test was made to determine the significance of the regression coefficients from zero. For wet soil this test showed significance at the one-percent level; for intermediate soil, at the 5 percent level; and for dry soil, no significance. As these data were obtained at different depths, the variation in bulk density is greater than would be expected at any one depth; however, the data do illustrate that, where bulk density variation exists, a significant moisture content-bulk density regression may be secured independent of shrinking or swelling of the soil.

As stated previously, of the 90 regressions based on random field sampling at Vicksburg, 28 were statistically significant. However, these regressions are affected by the fact that soil weight per unit volume is a common element in both variables, and by the correlation between moisture content at a given tension and amount of pore space independent of soil shrinking or swelling. It is believed that the effect of moisture content on bulk density of these soils is small enough to be disregarded with respect to gravimetric sampling.

If random field sampling will not give a valid estimate of the change of bulk density with change in moisture content, how can it be accomplished? Several approaches are possible. A variation of the field sampling technique has been suggested: intensive random sampling of an area when it is wet and again when it is dry to provide an average bulk density for each condition. The difference between the two averages would be a measure of the swelling or shrinking which had occurred. A second approach involves the measurement of changes in elevation of the ground surface with change in moisture content (5). A third possibility lies in methods of determining field bulk density *in situ*, such as the gamma-ray scattering method now being developed (2).

Summary

It has been shown that even though a change in moisture content may really change the volume occupied by a given soil mass (whose bulk density will also change), this change will not affect determination by electrical-resistance methods of inches of water in a given soil mass or layer. This is so because the product of variable bulk density times variable volume or thickness of a given soil mass remains constant and independent of moisture content.

It is further indicated that even with gravimetric sampling it is unwise to attempt to adjust bulk density for variation in moisture content (especially percent by weight) because bulk densities determined under dry conditions are likely to be inaccurate, and because such inverse relationships as have been found are due only in part to the shrinking and swelling of soil.

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CORE VS. BULK SAMPLES IN SOIL-MOISTURE TENSION ANALYSIS

W. M. Broadfoot 1/

The usual laboratory procedure in determining soil-moisture tension values is to use "undisturbed" soil cores for tensions up to 60 cm. of water and bulk soil samples for higher tensions. Low tensions are usually obtained with a tension table (2) and the higher tensions by use of pressure plate apparatus (3).

In tension analysis at the Vicksburg Infiltration Project some soils had higher moisture contents at 1/3 atmosphere tension than at 60 cm (.06 atmosphere). This was noted particularly in fine-textured soils, and was thought to be related to the difference in relative disturbance of the soil samples used under the two tensions. Accordingly, a comparison was made of the moisture contents of core and bulk samples at various tensions.

Experimental Procedure

The procedure used in preparing samples, and the treatment during the determination, varied for two sets of samples. The procedure used at first (called A for convenience) was later abandoned in favor of procedure B, which seemed to yield more accurate results. However, the results from procedure A are comparable for the purpose of this study and are therefore included.

Procedure A.--Five pairs of samples, core and bulk, were obtained from each of three soil types: Commerce silty clay, Briensburg silt loam, and Bosket very fine sandy loam. The cores were obtained in stainless steel rings, 2-3/4 inches in diameter and 3/4-inch in depth, which were driven into the surface 3-inch soil layer by a Coile-type driving head or sampler (1). Each bulk sample was taken close or adjacent to its corresponding paired core.

1/ R. A. Tobiaski, D. A. Ellison, and R. S. Pierce assisted in securing the field samples and making the laboratory analysis.

Bulk samples were prepared in the laboratory by hand crushing and passing through a U. S. Standard 9-mesh sieve. The soil was placed in the rings, one end of each ring having previously been covered with a filter paper and cheesecloth held in place with a rubber band. The paper insured against loss of fine particles of soil while the cloth held the soil in place. The cores were also covered by cloth and paper. Samples thus contained in rings were placed in a shallow pan of water and allowed to soak until saturated.

The paired samples were run simultaneously at tensions of 5 and 60 cm. of water on the tension table, at 0.1, 1/3, and 1 atmosphere pressure in pressure cells using common asbestos board as a membrane, and at 3 and 15 atmospheres pressure with Visking sausage casing as a membrane. After they came to equilibrium at each of the tensions, the samples were weighed. After this cycle, as a check on the first determinations, the same samples were rerun at 5 and 60 cm. water tension. Oven-dry weight was obtained after the second 60 cm. water tension determination, and moisture percentage was then calculated for all tensions. Controls or blanks were run on the filter paper, cheesecloth, and rubber bands to determine the moisture content of these materials at the various tensions.

From 6 to 24 hours were allowed for moisture to reach equilibrium in samples on the tension table, and from 24 to 48 hours for samples in the pressure cells. The tension table was covered tightly with oilcloth to prevent evaporation.

Procedure B.--Soil-moisture values secured from procedure A, even though useful for comparative purposes, were somewhat greater at high tensions than data previously obtained on two of the same soils. This indicated that the paper-plus-cheesecloth combination was so thick that it caused the water columns or film to break when the moisture content was reduced. When the water columns were broken, equilibrium was reached prematurely.

Procedure B differed from A in that only one thickness of cheesecloth was used to hold the sample in the ring, and it was removed entirely during the determinations at 3 and 15 atmospheres. In these high-tension runs the soil was directly against the Visking sausage membrane. Moisture content was determined simultaneously for paired samples of soil at the same tensions as stated above.

Sixteen paired samples, taken from various depths of an unidentified loess silt loam near Poplar Bluff, Missouri, were used in the comparison by procedure B. The cores were taken in brass rings, 2

inches in diameter and 1/2 inch in depth, using a core sampler described on page 10 of this Occasional Paper.

Results and Discussion

Results of the comparison are shown in table 1. Moisture contents of the bulk samples at 5 cm. of water (.005 atmosphere tension) were significantly higher than those of the cores, ranging from 34 percentage points higher for the Commerce silty clay to 10 points higher in the very fine sandy loam soil. As tension was increased to 60 cm. (.06 atmosphere), the difference decreased, but was still significantly higher. The difference in the means remained significant throughout the intermediate tension range of .1 to 1 atmosphere, except for the very fine sandy loam. For the sandy soil, bulk samples were significantly higher in moisture content only up to .1 atmosphere tension.

At 3 and 15 atmospheres, it was only in the Commerce silty clay that bulk samples had significantly higher moisture contents than the cores. At the same high tensions, cores of the very fine sandy loam and the silt loam from Missouri tended to have slightly higher moisture contents than the corresponding bulk samples. Differences, however, were not significant.

The bulk samples that were repeated at 5 cm. water tension dropped considerably in moisture content. The Commerce silty clay

Table 1.--Comparison of mean moisture content in percent by weight for core and bulk samples at different tensions

Tensions (atmospheres)	Procedure A									Procedure B; loess silt loam (Missouri)		
	Commerce silty clay			Briensburg silt loam			Bosket very fine sandy loam					
	Core	Bulk	Difference	Core	Bulk	Difference	Core	Bulk	Difference	Core	Bulk	Difference
	- - Percent - -			- - Percent - -			- - Percent - -			- - Percent - -		
0.005	36	70	34**	43	66	23**	36	46	10*	40	60	20**
.06	32	48	16**	38	50	12**	31	37	6*	30	44	14**
.1	32	42	10**	34	43	9**	28	35	7**	27	35	8**
1/3	30	40	10**	32	41	9**	25	28	3	25	31	6**
1	30	38	8**	32	37	5**	27	25	-2	23	27	4*
3	28	32	4**	26	30	4	17	15	-2	17	15	-2
15	23	29	6*	20	24	4	12	10	-2	12	10	-2
1/.005	35	47	12**	41	49	8**	39	39	0			
1/.06	32	40	8**	38	42	4**	35	34	-1			

**Difference in means significant at 1 percent level.
* Difference in means significant at 5 percent level.
1/Second run.

went from 70 percent to 47 percent, the Briensburg silt loam from 66 to 49 percent, and the Bosket very fine sandy loam from 46 to 39 percent. The corresponding cores remained about the same on the second run as on the first. The difference in moisture content between the rerun core and bulk samples remained highly significant in the Commerce and Briensburg soils but was not significant in the Bosket soil.

The samples repeated at 60 cm. water tension showed the same moisture content for the cores as was obtained on the first run, but a drop in value on the bulk samples of eight percentage points on the heavier soils. Again the difference was highly significant between the core and bulk for the Commerce and Briensburg soils, and was not significant for the Bosket.

Conclusions

At tensions up to 1 atmosphere, bulk samples retain more water than core samples. There is less difference in sandy loam soils than in heavier soils. At higher tensions up to 15 atmospheres it makes little difference whether cores or bulk samples are used in tension analysis, inasmuch as the values obtained show no consistent difference.

Because the core samples represent the "undisturbed" or field condition of the soil, it seems that cores should be used in tension analysis at from 0 to 1 atmosphere.

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DEVICES TO FACILITATE KING-TUBE SOIL-MOISTURE SAMPLING

Edwin R. Ferguson and William B. Duke[1]

The King-tube (or the modification by Veihmeyer) is widely used for obtaining soil samples for moisture content determinations.[2] These samples are usually collected from various depths and are often taken at frequent intervals. To expedite soil-moisture studies being conducted in east Texas, two devices were developed: a measuring trough for dividing the soil core into depth increments, and a box for storing and carrying the soil sample cans.

Measuring Trough

The trough (fig. 1) is designed to stand in a slanting position so that the soil core can be slid from the King-tube with a minimum of disturbance. The profile position of the core can then be easily measured by a yardstick that is permanently fastened to the inside of the trough.

The trough is simple and inexpensive to construct. The bill of materials is given below. All lumber is surfaced on four sides. Dimensions are nominal.

2 trough sides, 1" x 4" x 40"
1 leg, 2" x 4" x 5"
1 leg, 2" x 4" x 12"
1 foot, 1" x 4" x 12"
1 1/4" plywood cover, 5-1/2" x 5-1/2"
1 3" strap hinge
1 yardstick

1/ East Texas Branch, Southern Forest Experiment Station.

2/ Veihmeyer, F. J. An improved soil-sampling tube. Soil Sci. 27: 147-152. 1929.

Figure 1. --Measuring trough in use.

Figure 2. --Plywood box for carrying soil sample cans.

The two forty-inch boards are nailed together at right angles to form the trough. The yard stick is tacked along the upper edge of the trough with its zero end flush with the lower end of the trough. The plywood gate is fastened across the zero end of the trough by a long woodscrew; the gate has sufficient play so that it rotates easily. The 2 x 4 pieces are notched to conform to the outside angle of the trough. The short piece is permanently fastened about three inches from the lower (zero) end. The long leg is attached to the trough with a 3-inch strap hinge. The piece of 1 x 4 x 12 is fastened on the base of the long leg to stabilize the trough. For carrying and storage, the long leg is folded forward under the trough.

To use the trough, the head of the King-tube is placed in the V against the gate, and the point of the tube is slowly elevated. At the same time, the soil is pressed gently with the thumb to break it away from the constricted end. The core slides free in the tube with the upper portion of the core resting against the gate. In most cases a sharp withdrawal of the tube along the V toward the upper end of the trough will slide the core out. Depths at which the profile changes in color and texture can be easily read from the fixed scale.

Soil cores at high moisture contents sometimes compress in length within the tube. In this event, the core can be separated into desired lengths by assuming equal compression throughout, or by identifying profile characteristics at known depths. After the core has been divided into the desired segments, the gate is flipped open, and the segments are slipped into sample cans.

To prevent the core from drying excessively while it is lying in the trough, the work should be done rapidly, and preferably out of direct sunlight and wind.

Box

The other device is a box with a sliding cover for carrying soil sample cans (fig. 2). This box was designed to carry 20 four-ounce cans. Besides facilitating the handling of samples, this box has greatly reduced the need for can replacement by providing protection from impacts.

The bill of materials for the box is as follows. Lumber is surfaced on four sides. Dimensions are actual.

2 sides, 3/4" x 2-1/2" x 13-3/4"
1 back, 3/4" x 2-1/2" x 9-7/8"
1 front, 3/4" x 1-7/8" x 9-7/8"
1 lid pull, 3/8" x 3/4" x 9-7/8"
1 bottom, 1/4" plywood, 11-1/2" x 13-3/4"
1 lid, 1/4" plywood, 10-7/16" x 13-1/4"
1 handle, piece insulated wire, 8-1/2" long

The sides and back have a groove (9/32-inch deep and 5/16-inch wide) cut 3/8-inch from the top edges, in which the lid slides freely. The parts can be fastened together with finishing nails or woodscrews.

TERMINAL PANEL FOR ELECTRICAL SOIL-MOISTURE INSTRUMENTS

B. D. Doss and W. M. Broadfoot

Since soil-moisture measurement with electrical instruments has come into fairly wide use, various devices have been developed to provide a rapid and reliable connection of the soil-moisture meter to the wires from the underground units. Among these devices, permanently housed multiple switches and a portable multiple plug for use with the fiberglas instrument have recently been described.[1/] These devices have conveniently served the purpose for which they were intended. However, it has been found that the same objectives can be obtained with a terminal panel that is much simpler in construction, sturdier, and does not require shelter from weather.

Description

The terminal panel is made of 1/4-inch Plexiglas, 2-3/4 inches wide and long enough to accommodate the number of terminals desired (fig. 1). Holes 3/16 inch in diameter are drilled in the Plexiglas at distances of 3/4 inch apart vertically and 1 inch apart horizontally. Brass machine screws 3/16 inch in diameter and 3/4 inch long are fastened in the holes with nuts, and lead wires from the moisture units are soldered to the screw heads. Temperature leads are connected to the left side, ground wires to the center, and moisture wires to the right side of the panel. Screw heads and wire connections on the back of the panel are painted with bakelite resin varnish for waterproofing and insulation. The terminal plates are mounted with screws on a stake.

A dual clamp--consisting of two battery clamps fastened together with Plexiglas--connects the meter with the terminals (i. e., the ends of the machine screws).

1/ Palpant, E. H., Thames, J. L., and Helmers, A. E. Switch shelters for use with soil-moisture units. Southern Forest Expt. Station Occas. Paper 128, pp. 21-30. 1953.

The moisture and ground leads from the meter are attached to this clamp. When readings are made, the meter dial knob is set on "moisture" and the clamp is attached to the unit terminals on the left side of the panel for temperature and subsequently to the terminals on the right for moisture readings. The dual clamp can be easily moved from one pair of terminals to another.

This terminal plate is being extensively used at the present time. Its simplicity of construction, sturdiness, and freedom from wear (it has no moving parts) have proven to be distinct advantages.

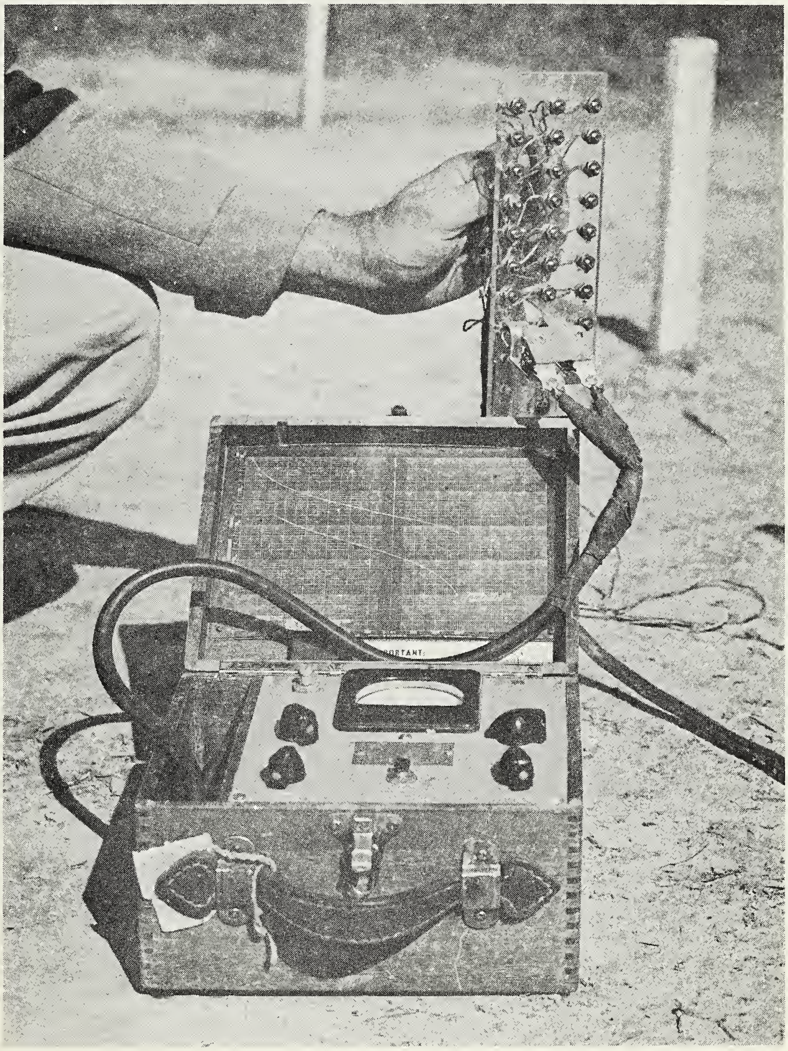

Figure 1. --Terminal panel with fiberglas soil-moisture meter.

PHONE-JACK TERMINALS FOR SOIL-MOISTURE UNITS

Frank Woods and Walt Hopkins[1/]

In west Florida, triple-contact phone jacks and plugs have been used for connecting the meter to the fiberglas soil units. One plug replaces the three alligator clamps with which the meter comes equipped. The jacks are mounted on a Plexiglas terminal panel (fig. 1).

Field use has proven the plug and jacks to be fast and reliable. Only one operation is required to make three contacts and there can be no confusion of leads. However, in making temperature and moisture determinations on each unit, it is necessary to throw the moisture-temperature switches to the proper positions. The jacks are simple to operate, and are less subject to deterioration than multiple-pole switches. They have no moving parts and a uniform contact is made each time a plug is inserted. The 1/4-inch diameter plugs and jacks are recommended; they can usually be obtained at electrical and radio shops.

The Plexiglas terminal panel must be tightly fastened to its support, because a strong pull is sometimes necessary to remove the plug. This panel should be coated with a non-conducting varnish to decrease the possibilities of short circuits.

A standardized wiring scheme for plugs and jacks is necessary if the same meter is to be used to read several stacks of units. A standardized scheme could be as follows: tip of plug--temperature; middle of plug--moisture; base of plug--ground.

1/ East Gulfcoast Branch, Southern Forest Experiment Station.

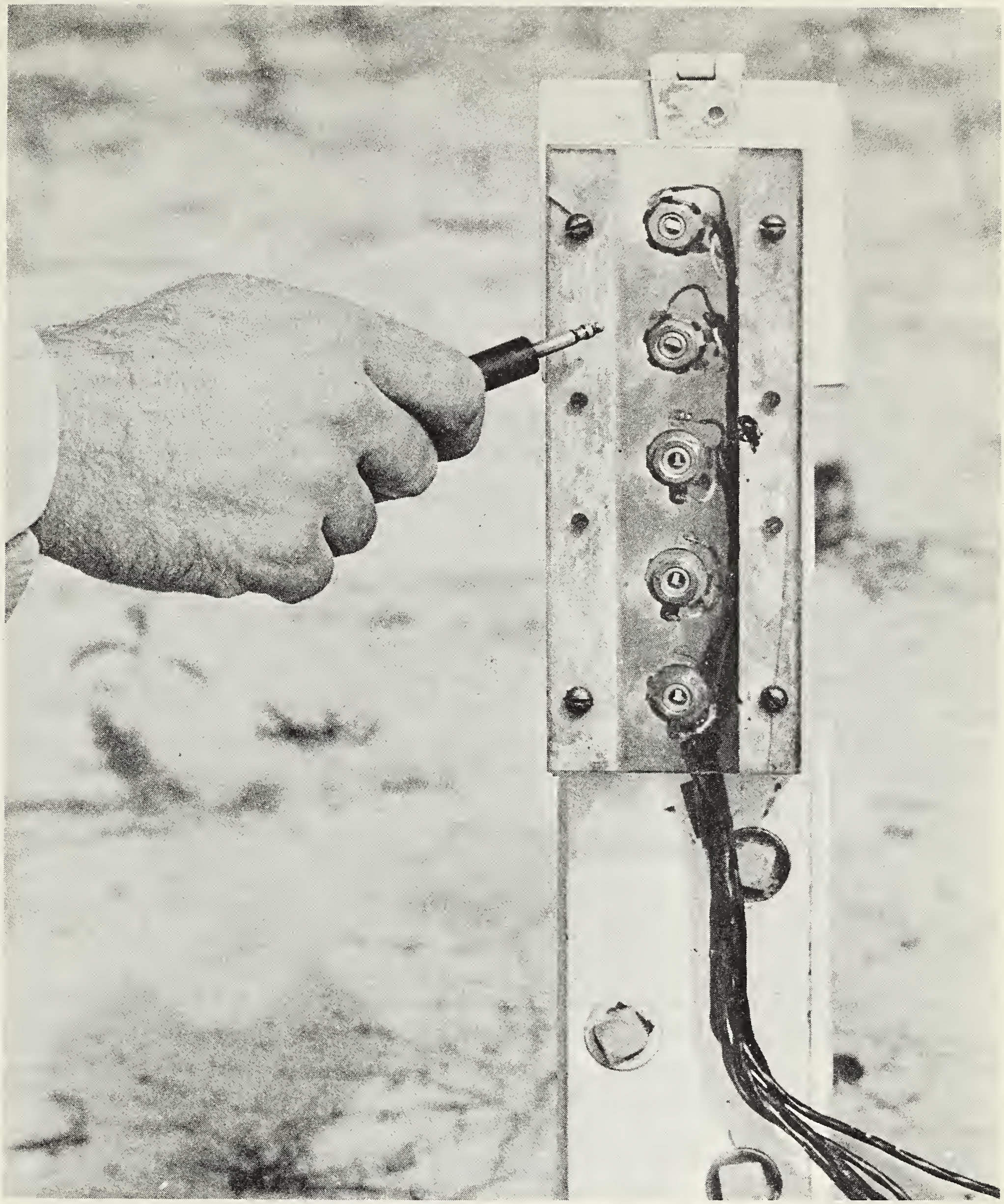

Figure 1. --Phone-jack terminals.

COMPARISON OF LABORATORY AND FIELD CALIBRATION OF FIBERGLAS MOISTURE UNITS

Charles A. Carlson

Several methods have been used for calibrating fiberglas soil-moisture units. Two laboratory methods, using prepared soil or cores, and one field method are described in the manual of instructions for the instrument (3). Subsequently, in a detailed study of the calibration method, the designers of the unit concluded that "field and laboratory calibration are in good agreement when the laboratory calibration is made in a natural soil core...." (4) In rocky soils a combined method has been used in which laboratory curves were adjusted on the basis of a few field measurements (1).

In a study of the soil-moisture regime in three soils in the vicinity of Vicksburg, Mississippi, preliminary work indicated that laboratory calibration with cores did not agree with field calibration (2). The comparison was not precise because the same moisture unit was not used in the field and laboratory calibrations of any one soil layer. Termination of this study, however, provided an opportunity to make a more rigid test, a comparison of laboratory and field calibrations of several of the units used in the field study.

Methods

In 1951, fiberglas soil-moisture units were installed in Loring silt loam, Collins silt loam, and Commerce clay soils at three-inch depth intervals in quadruplicate stacks. Periodically for six months, duplicate soil-moisture samples were taken at random within a 6- by 6-foot plot surrounding each stack. The soil-moisture contents were plotted against corresponding resistances of the units, and a curve was drawn. Details of installation and field calibration are described elsewhere (5).

Units from single stacks in the Loring and Commerce soils, and from four stacks in the Collins soil, were used for laboratory calibration. Calibration cans were made from eight-ounce moisture cans, 3 inches in diameter and 2 inches high, by cutting disks 2-1/4 inches in diameter from the bottom and lid and placing a hundred-mesh brass

screen backed by 1/4-inch hardware cloth on the inside of the can against the rim of the openings.

In order to facilitate removal of the units, a hole was dug at the position of the auger hole that had been used to install the units originally. This hole was filled with water several times so as to wet the soil about the units. A calibration can was then hammered into the soil surrounding each unit; the wires of the units passed through a hole in the screen in the base of the can. The can with enclosed soil core and unit was then dug out, trimmed, and capped with a lid. Units disturbed in this operation were not used in the laboratory calibration. Twenty-two cores were obtained, five at the 4-1/4-inch depth, six at the 7-1/2-inch depth, five at the 10-1/2-inch depth, four at the 15-inch depth, and two at the 21-inch depth. Fourteen of these were from the Collins soil and four each from the Loring and Commerce soils. In order to determine the effects of swelling, if any, half of the cans were bound with wire.

The cores were saturated from the bottom and left, not quite submerged, in distilled water overnight. Concurrent weights and resistances were measured once or twice a day as the cores air-dried. When a unit reached a resistance of about one hundred kilohms, the core was sealed in a sixteen-ounce can to prevent further drying. After all samples were dried, the cores were resaturated and the drying process repeated. Three successive drying calibrations were conducted.

After the third cycle, the cores were slowly wetted by a daily addition of ten cubic centimeters of distilled water to the top surface of each core. Weights and resistances were measured just before the water was added. Following the addition, the cores were equilibrated in sealed cans until the next measurement. This process was continued until water dripped from the core base, after which the cores were saturated by standing them in water. Oven-dry weights of the soil cores were then determined and soil-moisture contents computed for each weighing of the cans.

The laboratory and field curves of each unit were plotted for visual and numerical comparisons. For the latter, resistances were selected at the low end, midpoint, and high end of the resistance range as reference points for computing moisture content differences between curves, using the field curves as standards. The moisture content differences at each given resistance were averaged by soil type, by depth, and for all samples.

One stack of units in the Collins silt loam had been calibrated in the laboratory before it was installed in the field (2). In this preliminary test the core container was smaller and had open ends bound with cheese cloth. The daily drying procedure included an overnight period in a humid chamber maintained at 98 percent relative humidity. Calibrations derived from this earlier test were compared with those from the present study.

Results and Discussion

Table 1 gives average moisture content differences, at three resistances, between the 22 sets of laboratory and field curves. For most of the combinations averaged, the laboratory values were wetter (indicated by positive values) than the field values at a resistance of 0.5 kilohm, and dryer (negative values) at a resistance of 50 kilohms. The lack of agreement between laboratory and field calibrations is also shown in figure 1, a typical family of calibration curves.

Generally, the first-cycle laboratory curve was closer to the field curve than the second-cycle curve (table 1). The second-cycle laboratory curve was from 0.5 to 2.8 percent wetter than the first-cycle curve at 0.5 kilohm resistance; and from 0.4 to 2.4 percent drier at 50 kilohms resistance. The second- and third-cycle curves usually fell close together.

At high moisture content, resistances tended to increase with successive drying cycles. This may have been due to a small gradual loss of dissolved salts with repeated saturations. At low moisture contents, the resistance frequently dropped somewhat after the first drying cycle. The reason for this is not known, but possibly the overnight saturation did not wet the soil fully after it had been thoroughly dried for the first time.

The displacement of laboratory curves differed by soil types. At 5 kilohms the first-cycle laboratory values for Loring silt loam were, on the average, 1.4 percent drier than the field values; Collins silt loam and Commerce clay averaged 3.4 and 1.1 percent wetter. For these soils, therefore, a single correction cannot be used to adjust laboratory to field curves.

Moisture content differences varied by depth also. The laboratory curves tended to be moister than the field curves with increase in depth, particularly at low resistances. The moisture difference at a

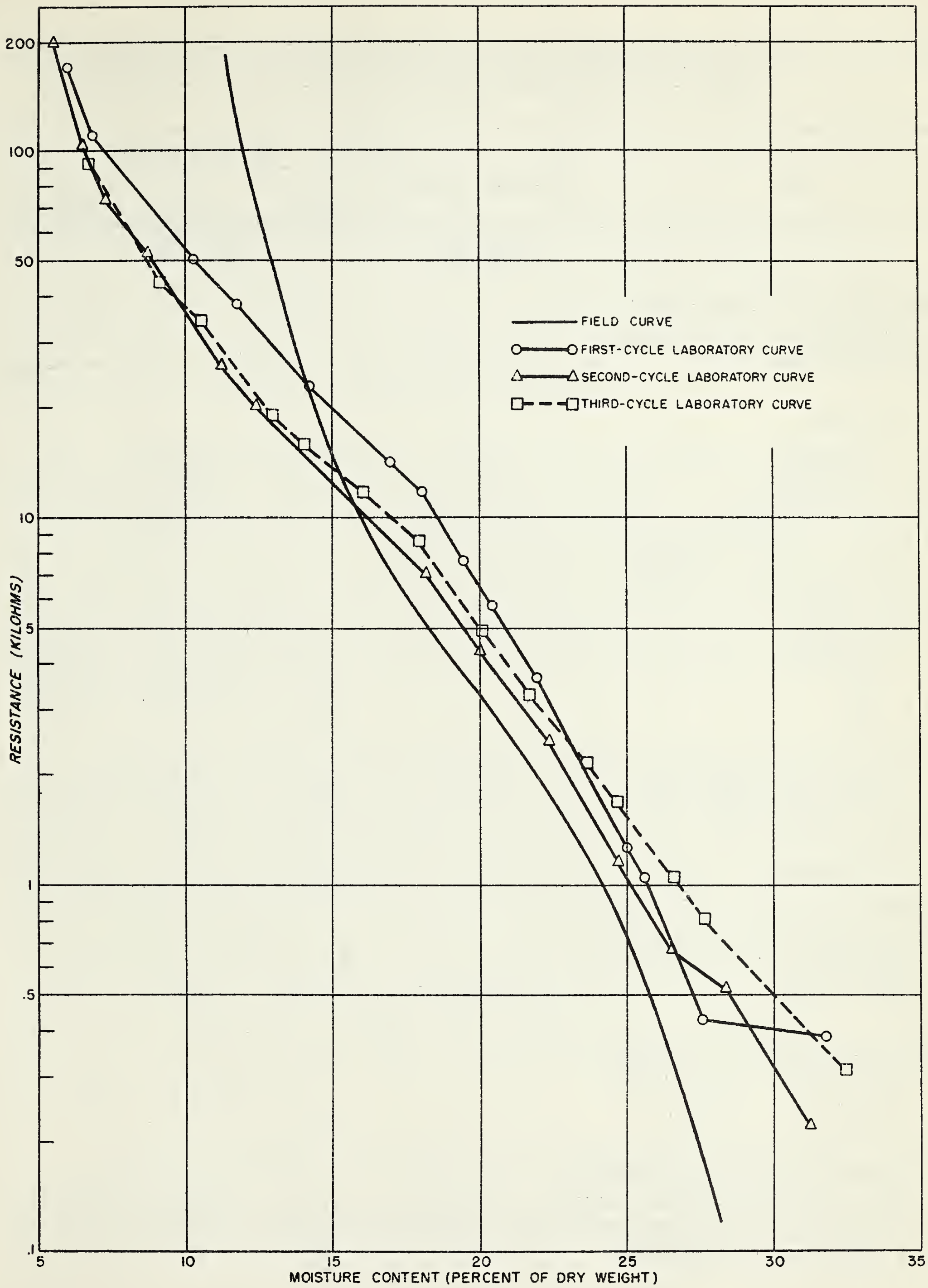

Figure 1.-- Typical family of curves, Collins silt loam, 7 1/2- inch depth.

Table 1. --Average soil-moisture content differences (as percent of dry weight) between calibration curves at given resistances

Item	Comparisons	Resistance		
		0.5 kilohm	5 kilohms	50 kilohms
	Number	- -	Percent	- -
Difference of first-cycle laboratory curves from field curves				
By soil				
Loring	4	-2.2	-1.4	0.1
Collins	14	2.6	3.4	- .2
Commerce	4	.2	1.1	-1.3
By depth (in inches)				
4-1/2	5	- .1	- .4	- .5
7-1/2	6	1.6	2.2	- .3
10-1/2	5	.8	2.2	-2.0
15	4	3.7	4.5	.6
21	2	4.0	1.8	...
Cans tied with wire	10	1.7	2.0	- .7
Cans not tied	12	1.2	2.2	- .2
All samples	22	1.5	2.1	- .4
Difference of second-cycle laboratory curves from field curves	22	2.8	1.2	-2.4
Difference of 1951 second-cycle curves from 1953 second-cycle curves	4	2.5	- .4	- .8
Difference of wetting curves from previous drying curves	22	-3.0	-3.2	1/ -1.4

1/ Average at 20 kilohms.

resistance of 0.5 kilohm ranged from -0.1 percent at a 4-1/2 inch depth to 4.0 percent at 21 inches (table 1). For units installed near the soil surface, laboratory calibrations agreed fairly well with field curves; for units placed deeper, the laboratory calibration was not satisfactory. The agreement at the surface may have been due to better aeration of the laboratory cores and of the surface soil in the field. Under these conditions, carbon dioxide can diffuse readily to the atmosphere. At lower depths, diffusion is restricted and the carbon dioxide level increases, thus bringing more salts (the bicarbonates) into solution (6), and consequently lowering resistances at given moisture contents. This would explain the greater discrepancy of the laboratory curves with increase of soil depth. Field conditions of aeration at lower depths would be difficult to duplicate in laboratory samples.

Another possible cause of differences in calibrations is the swelling of cores. This swelling has been observed frequently and may be expected because in the laboratory the soil is not confined as it is at lower depths in the field. To determine the effect of swelling, ten of the calibration cores were bound with wire, so as to secure the lids, and 12 were left untied. No swelling or lifting of the lids was observed in any of the cans during the test. Results indicated that tying cans with wire had little effect (table 1). Apparently swelling was not a factor in this test.

With the earlier laboratory calibrations, before the units had been installed in the field, the cores had more opportunity to swell because the ends of the cans were covered only by cheesecloth. This is evident in the comparison between second-cycle curves (table 1). Swelling, and increased water retention of 2.5 percent, is indicated at the lowest resistance of the earlier calibration. The agreement of the curves at high resistances is notable (-0.4 percent at 5 kilohms and -0.8 percent at 50 kilohms), considering that the laboratory calibrations were made by two different methods, 2-1/2 years apart. This agreement confirms the earlier conclusion that equilibration of laboratory cores is not necessary (2). Typical curves of the two calibrations are shown in figure 2.

Further complicating the use of laboratory calibration is the error introduced at high resistances by the moisture gradient formed within the core (2). This gradient was produced because the ends of the core dry more rapidly than the center (where the moisture unit was situated). The unit consequently had a lower resistance than was justified by the gross moisture content of the sample. As a result, the laboratory curve was drier than the field curve in the high resistance range.

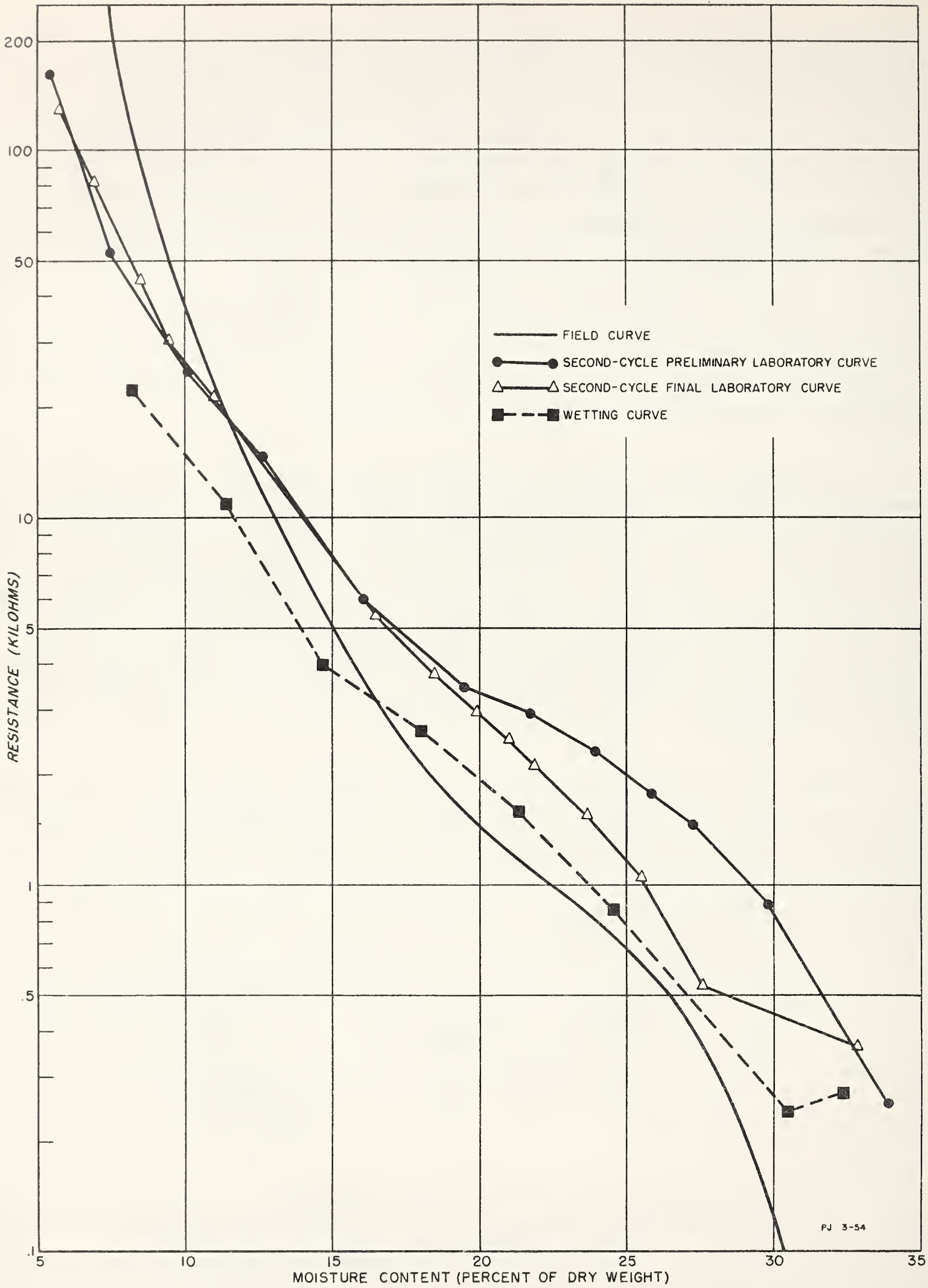

Figure 2.-- Calibration curves before and after field installation, and with wetting. Collins silt loam, 4 1/2-inch depth.

The wetting curves were displaced to the left of the drying curves but rejoined at saturation (fig. 2 and table 1). This hysteresis may explain part of the overall difference between the standard laboratory and field curves. Laboratory curves generally are drying curves throughout. Field curves are based on soil samplings interspaced by rains and drainage and depletion periods, and thus may have been a combination of drying and wetting curves. In this study the laboratory wetting curve tended to follow the field curve at low resistances, whereas the drying curve followed more closely at high resistances.

Conclusions

Laboratory calibration of fiberglas soil-moisture units in soil cores did not coincide with the field calibration. Probable causes for the discrepancy are leaching of some of the solutes from the sample, change in aeration and the resulting change in carbon dioxide and bicarbonate concentration in solution, hysteresis between wetting and drying of the soil, moisture gradients in the laboratory cores, and, in some procedures, swelling. It is doubtful that field conditions can be so closely duplicated in the laboratory that field curves can invariably be reproduced. Field calibration is therefore recommended because of the inherent errors in laboratory calibration. Field calibration also reflects more nearly the average moisture content over an area, as opposed to the point sampling associated with laboratory calibration (5).

The laboratory curves do give the general shape and range of the field curves and can be used directly for studies of average field moisture content in which an accuracy of about 3 percent is satisfactory. Where soil-moisture studies are conducted in rocky soils or under pavements, laboratory calibration must be used. But where soil samples can be secured, field calibration is recommended.

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A CORE METHOD FOR DETERMINING THE AMOUNT AND EXTENT OF SMALL ROOTS

Charles A. Carlson

Several root extraction methods utilize soil cores for the determination of root concentration (1, 2, 4). These techniques are relatively quick and simple as compared with those designed to measure the full extent of individual root systems (3). As commonly applied, however, methods generally involve root-washing techniques that lose unknown amounts of small roots. Since the small unsuberized roots absorb most of the water and nutrients, they should be measured. A method using cores was therefore devised to catch the small roots--those 0.02 to 2.0 millimeters in diameter.

The method entails the procurement of a known volume of soil at a prescribed depth; separation of roots from soil by suspension in a dispersing solution; collection on a 100-mesh sieve which eliminates the fine soil particles; decantation to separate roots from coarse soil particles; measurement of fresh weight, fresh volume, and dry weight; and ashing the sample to determine the correction for adhering soil particles. The average diameter of fresh roots is determined with a microscope, and aggregate length and area of root surface are computed.

Procedure

Core samples were taken from a hole dug with a 5-inch post-hole digger to within one inch of the desired depth. A core sampler with a removable sleeve (about 2-3/4 inches in diameter and 3 inches high) was driven into the soil at the bottom of the hole. After extraction, the ends of the core were trimmed flush with the sleeve, and the core was sealed in a 16-ounce can. Samples at various depths and locations were taken. Litter and organic matter were scraped off the soil surface to prevent contamination of the top sample.

Each sample was soaked for 3 days in a 5-gallon bucket containing about 1 gallon of a solution of 0.02 N sodium hydroxide and 0.005 N sodium oxalate. The sample was broken by hand and the mixture stirred occasionally to break the aggregates and to suspend the soil particles.

The suspension was then diluted with 2 gallons of water, and poured slowly through a 100-mesh sieve. A small stream of water was played on the material to help wash the fine particles through the screen. Dilution and use of the water stream were necessary to prevent clogging of the fine sieve holes. Rhizomes, trash, and roots greater than about 2 mm. in diameter were picked from the sieved material and discarded.

A small stream of water was employed to push the residue on the sieve into a beaker. Floating debris, most common in surface samples, was skimmed off. The roots were then stirred and, after a few seconds during which the sand settled to the bottom, were decanted back to the 100-mesh sieve. Decantation was repeated three or four times to complete the separation of roots from sand. The roots were then transferred to a wide-mouth picnometer for volume determination. Next, the roots were placed on a small 100-mesh screen mounted on a vacuum flask. A rubber stopper was pressed against the roots to help expel excess water, and the fresh weight determined. The sample was then dried in an oven at 65°C. and weighed.

Finally, the sample was put into an evaporating dish and fired in a muffle furnace at a dull red heat, about 650°C. The ash was digested thoroughly in boiling concentrated hydrochloric acid, and the residue washed by decantation, dried, and weighed. The fresh weight and the volume of roots were corrected for residue by subtracting the weight of ash or the calculated volume. A specific gravity of 2.65 was assumed for the residue.

To measure root diameter, a subsample of fresh roots was mounted on a glass slide and all roots measured that crossed a selected transect of the slide. Roots were magnified twelve times; measurements were made by using a graduated eyepiece in a microscope. Four or five subsamples were measured with two transects per slide. A total of 200 to 300 root diameters was measured per sample. The average diameter was determined, and the total surface area and the aggregate length of the roots in the sample were calculated.

The effect of screen size on the collection of roots was checked. Samples were passed through a nest of three sieves--12, 28, and 100 meshes per inch. The root diameter distribution was determined for the material caught on each sieve.

The effects of the chemical dispersing agent on the roots were tested by dispersing three cores in the chemical solution and three matching cores in tap water, and determining the average diameter, moisture content, and density of the fresh roots for each treatment.

Discussion

The washed root samples apparently included most of the fine roots. Few fragments were visible in the water that passed through the 100-mesh sieve. However, since the finest roots and the root hairs are less than 0.149 mm. in diameter (i.e., the size of the sieve holes), material could be lost even with the 100-mesh sieve.

To the eye, the bulk of the material on the sieve resembled debris. Under the microscope, most of it was seen to be root segments, but some small seeds or decayed organic matter was present and introduced error into the root determination. Because of the opportunity for such contamination, this method is not adapted to soils high in partially decomposed organic matter.

Numerous strands or filaments, approximately 0.010 to 0.020 mm. in diameter, were also visible through the microscope. Since some of these strands were branched, indicative of fungi, none less than 0.020 mm. were measured for diameter. Thus, the root hairs, which have a nominal diameter of 0.015 mm., were excluded from these measurements. Weight and volume determinations, however, included the filaments.

The diameter distribution of roots passing through the nest of three sieves is given in table 1. The diameter distribution of the roots was about the same for each sieve; no segregation occurred. Although the majority of the roots caught on any one sieve had diameters as small as or smaller than the openings in the 100-mesh sieve, the lengths of the segments were greater than the openings. The length apparently impeded passage through the sieve. The smallest-meshed sieve, used by itself, retained more roots than either of the larger sieves because it caught shorter segments.

The chemical dispersing agent had no apparent effect on the root characteristics. Diameter, moisture content, and density were the same with or without the chemical treatment (table 2).

Root concentrations for these samples averaged 1.7 percent volume of fresh roots per volume of soil. Aggregate length, as calculated from average root diameter, was about 90 meters per 100 cc. of soil. Aggregate surface area of the roots was 416 square cm. per 100 cc. of soil. Thus, though the root volume was small, the aggregate length and surface area per unit volume of soil were considerable.

Table 1. --Distribution of roots passed through nest of sieves. Average of two samples

Root diameter (millimeters)	Material collected --on 12 mesh	--through 12 on 28 mesh	--through 28 on 100 mesh
	- - - Percent - - -		
0.02 - 0.10	46	38	32
.11 - .20	30	31	46
.21 - .30	16	19	16
.31 - .40	6	4	4
Greater than .40	2	8	2
Average root diameter	0.16 mm.	0.19 mm.	0.16 mm.

Table 2. --Effect of soil dispersing agent on root characteristics

Treatment	Average diameter	Moisture content (fresh weight basis)	Density
	Mm.	Percent	Grams per cc
Oxalate-hydroxide			
Sample 1	0.16	75.9	1.13
2	.16	74.9	1.13
3	.14	71.5	1.16
Tap water			
Sample 1	.18	74.8	1.17
2	.17	78.2	1.13
3	.14	73.2	1.16

Data obtained by this proposed method were compared (table 3) with those from the study by Dittmer. For the comparison, Dittmer's data were converted to measurements of 100 cc. of soil. The two studies give comparable results, considering that the method proposed here excludes roots and filaments smaller than 0.020 mm. in diameter because of the probable contamination by fungi.

Table 3. --Root characteristics by two sampling methods

Item	Sample	Average diameter	Aggregate length	Aggregate area	Volume
	Number	Mm.	Cm.	Sq. cm.	Cc.
Vicksburg method 1/					
Herbaceous on clay soil	6	0.135	17,228	730	2.53
Herbaceous on silt loam soil	6	.160	9,020	458	1.66
Hardwoods on silt loam soil	8	.186	5,682	332	1.54
Dittmer's method 2/					
Oats					
Roots	2	.225	658	46	.26
Root hairs	2	.013	117,900	494	.16
Rye					
Roots	2	.245	921	72	.43
Root hairs	2	.015	231,500	1,096	.41
Bluegrass					
Roots	2	.176	5,524	306	1.35
Root hairs	2	.010	740,700	2,258	.55

1/ Three- to 6-inch depth; excludes roots and filaments less than 0.020 mm. in diameter.

2/ Zero- to 6-inch depth.

In summary, this method appears useful in studies with a large number of samples in which volume or weight of small roots is desired. Measurements for the average diameter are tedious but necessary if length or surface area is needed.

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